Acceptance of Supply Security and Blackouts in the Context of Climate Protection and Nuclear Energies in Germany

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1 Introduction

In his *Review on the Economics of Climate Change*, Stern (2007) quantified the consequences of a climate change monetarily and thus created a measurability between two of the three energy policy goals, environmental sustainability and affordability. Stern's argument is that the consequences of non-action are more expensive than costs of action to protect the environment.

In reaction to this argument, the German electricity system is engaging in a very fundamental transition called *"Energiewende"* from a fossil towards a renewable supply. The goals of the government are to increase the shares of renewables to 35 percent by 2020, to 50 percent by 2030, to 65 percent by 2040, and finally to 80 percent by 2050, see BMWi and BMU (2010). In addition to these efforts to integrate renewables and following the events of the nuclear catastrophe in the Japanese prefecture of Fukushima, the German government decided (once again) to completely phase out nuclear energies by the year of 2022, see BMJ (2011).

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Facing the government's ambitious plans, more and more concerns regarding the security of supply are being expressed. The goal of this study is to contribute to a measurability of the third goal of energy policy, supply security, by quantifying the consequences of blackouts monetarily in analogy to the work of Stern. In this work, the focus lies on the costs of blackouts for private households. Moreover, I sought to link supply security to the government's goals of an increasing share of renewable energies and a nuclear phase out. I analyzed public acceptance of supply security in context of the topics climate protection and nuclear phase out.

To enable a better understanding of this topic, I start by giving a short overview and background information on the estimation of outage costs in the scientific literature (section 2) before presenting the data (section 3), the model and the simulation (section 4) used to estimate outage costs and public preferences on supply security in the context of climate protection and a nuclear phase out. Eventually, I present the results of the estimations (section 5) and finish with a discussion on the results' implications (section 6) and concluding remarks and outlook (section 7).

2 Theoretical background on the estimation of outage costs

Like in all markets in which supply fails to satisfy demand, interruptions of power supply have a loss of welfare as consequence. Typically, costs of blackouts are treated as being equal to losses of consumer surpluses neglecting losses of producer surpluses. Under the assumption of an inelastic demand curve for electricity, this seems to be a justified simplification.

A popular monetary figure in the scientific literature often associated to outage costs is the so-called *Value of Lost Load* (VOLL). According to Stoft (2002), VOLL represents the average costs per unit of unserved electricity to consumers due to power outages. The VOLL is a figure that is expressed in monetary units per unsupplied energy unit of electricity like EUR/kWh, etc. The VOLL can, therefore, be considered as the average loss of consumer surplus (CS) per unit of electricity consumption (EC), see Figure 1.

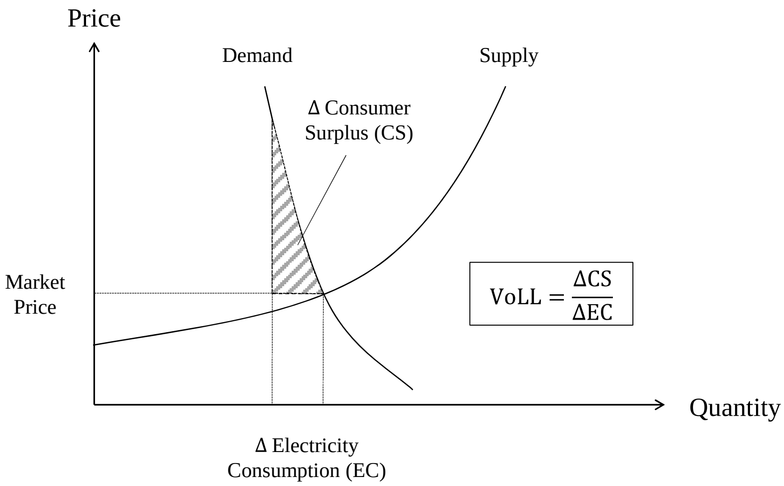

Figure 1: Electricity Market and Value of Lost Load

Blackouts can have such different impacts on consumers that it is reasonable to analyze outage costs for the different groups of electricity consumers. Also, outage costs can cause damages in different areas within a consumer-group. In this study, my focus is electricity consumers in private households. For this consumer group, I define four basic categories of possible areas that can generally be affected by outages.

- Immediate costs, such as data losses,
- Direct costs that accumulate over time, such as spoiling food,
- Indirect costs with the losses of free time opportunities, such as hobbies,

- Losses of comfort, such as the loss of a warm water supply.

2.1 Methods of outage cost estimation

In a previous work, see Praktiknjo et al. (2011), I analyzed the most common methods used in the literature to estimate outage costs. In this section, I shortly summarize the key findings to give a short overview of the scientific methods.

According to Sullivan and Keane (1995), methods to estimate outage costs can generally be allocated into three types:

- Methods based on macroeconomic models

  Outage costs studies based on macroeconomic models rely on electricity as input and on macroeconomic indicators (such as the gross domestic product, for example) as output. The availability of data depends on the availability of macroeconomic statistics.

- Methods based on revealed preferences (market based)

  Studies based on revealed preferences, sometimes also called market-based studies, quantify the outage costs by analyzing actual consumer choices made in the past regarding power services with different degrees of reliability. However, data for this type of studies is often very limited because a sufficient number of alternatives in consumer choices regarding concerning service reliability and costs is required.

- Methods based on stated preferences (surveys)

Studies based on stated preferences determine outage cost by analyzing responses from surveyed individuals to questions regarding power outages and costs. In these surveys, hypothetical power outage scenarios are used to collect the necessary data. Furthermore, these studies can be categorized in two different kinds of studies, depending on how the individuals are asked to estimate their costs. The consumers are either asked to directly estimate outage costs or to choose between different scenarios in which interruption cost are later derived from the choices made.

For further information on methods to estimate outage costs, see Sullivan and Keane (1995), Bateman et al. (2002) and Bjorkvoll et al. (2011).

2.2 Willingness to pay and willingness to accept

There are generally two kinds of empirical practices for studies based on stated preferences to obtain costs figures for reductions in the availability of a certain commodity such as electricity. The first one is the analysis of the maximum amount of money an individual would be willing to pay (WTP) to avoid the reductions. The second one is to figure out the minimum amount of money an individual would be willing to accept (WTA) as a compensation for the unavailability of the good.

Early studies in the field of economics suggested that WTA and WTP should be identical in theory, see Freeman (1979) or Thayer (1981). Empiric studies however often show that there are very often large disparities between WTA and WTP with WTA being higher than WTP. Hanemann (1991) derives a theory for these differences from the Slutsky equation that describes demand changes due to price changes with an income effect and a substitution effect. He suggests that the disparities in WTA and WTP can also be explained with an income effect, but more importantly with a substitution effect.

- Income effect:

  The higher the income elasticity for the considered good (a raise in income will trigger a relatively high raise in demand), the larger the differences of WTA and WTP will be.

- Substitution effect:

  The lower the (Allen-Uzawa) elasticity of substitution for the considered good towards other goods (the harder it is to find substitute goods for the good that is being limited), the larger the differences of WTA and WTP will be.

Hanemann (1991) shows in his works that the substitution effect has a far greater influence on disparities between WTA and WTP compared to the income effect. He concludes that these disparities indicate that all other available goods are rather imperfect substitutes for the considered good. For further details on microeconomic theory and the Slutsky equation see Varian (2009).

3 Data collection and online survey

3.1 Collecting data with an online survey

Because of the higher degree in freedom, I decided to use the stated preferences method in this study to estimate outage costs in private households. I carried out two online surveys s_1 and s_2 in 2011 over a total time period of six months from the beginning of January to the end of June. Eventually, a total of $n(s_1 \cup s_2)=841$ individuals participated in either of the surveys. The first survey s_1 (with $n(s_1)$=657 participants) was carried out ex-ante and the second survey s_2 (with $n(s_2)$=216 participants) was carried out ex-post the nuclear catastrophe in the Japanese city of Fukushima in March 2011. Out of the $n(s_1 \cup s_2)$ = 841 participants, $n(s_1 \cap s_2)$=32 individuals participated in both, s_1 and s_2.

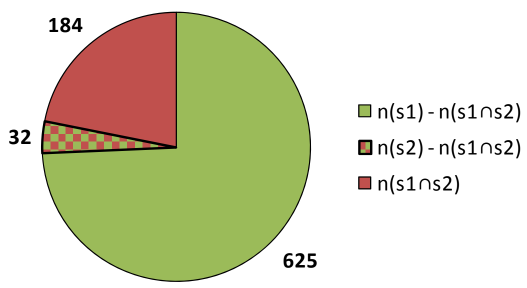

Figure 2: Number of participants in the surveys

I designed and programmed both surveys as HTML internet pages with CGI scripts written in the programming language Perl and used SQL databases to store the participants' entries. I programmed the CGI scripts in a way that multiple data entries from one individual were avoided.

In order to collect the necessary data to estimate outage costs, hypothetical power outage scenarios were employed in s_1 and s_2 with different interruption durations of 15 minutes, 1 hour, 4 hours, 1 day and 4 days.

With these scenarios, the surveyed individuals were asked to estimate both,

- their willingness to pay (WTP) to avoid these power outages ex-antes (e. g. with a backup generator), and
- their willingness to accept (WTA) monetary compensations for power outages ex-post (e. g. from their electricity provider).

I therefore chose the alternative to let the individuals estimate their costs directly for reasons of higher degree in freedom and brevity of the questionnaire. Furthermore, the individuals were asked to provide additional information. An overview of the information gathered in the two surveys is to be found in Table 1 and Table 2.

Table 1: Further information asked in the surveys

S1	**Inconveniences due to blackouts**
	Spoilage of food
	Limitation of household activities for the duration of the power outage
	Data losses and reconfiguration of electrical devices
	Absence of heat and hot water supply
S2	**Following the nuclear catastrophe in Japan**
	Preferences on supply security and the importance of a nuclear phase out
	Preferences on supply security and the importance of climate protection
S1 and S2	**General information**
	Households size (number of adults and children)
	Electricity consumption and accounting period
	The individual's and the total household's monthly net income
	Weekly working hours of the surveyed individual
	Subjective estimation of dependency on electricity for free time activities
	Type of building the individual is living in

Table 2: Choices regarding supply security, climate protection and a nuclear phase out

1	Climate proctection/a nuclear phase out is much more important than supply security
2	Climate proctection/a nuclear phase out is more important than supply security
3	Climate proctection/a nuclear phase out is equally important to supply security
4	Supply security is more important than climate protection/a nuclear phase out
5	Supply security is much more important than climate protection/a nuclear phase out

3.2 Economic Survey of Private Households (EVS)

The Economic Surveys of Private Households *"Einkommens- und Verbrauchsstichprobe"* (EVS) are official statics of the German Federal Statistical Office DESTATIS regarding the living conditions in Germany. Most of the information presented in this section is from the quality report of the EVS 2008 from DESTATIS (2012).

The EVS is a census that is repeated every five years and was lastly carried out in 2008. The data from the 2008 EVS were published in late 2010. The goal of the EVS is to give an overview of socio-demographic and socio-economic characteristics, incomes, expenditures, assets and liabilities, possession of commodities and housing situations of the German population. The surveyed entities are households with a permanent address in Germany and a monthly net income of below 18,000 Euro.

The goal is to select 0.2 % of the population's households proportional to each of the 16 Federal States in Germany which results in a total of 77,648 selected households in 2008. Furthermore a quota system is used for the attributes household type (single, family, etc.), social situation of the principal income earner (employee, self-employed person, etc.), and monthly household net income. Participation in the EVS is voluntary and households that decide to participate in the written survey are offered financial compensations. Nevertheless, not all households finish the survey. In the 2008 EVS a total number of 55,100 households finished the survey.

The census claims very high representativeness and data quality. Many important political decisions are based on these statistics such as the standard rates for unemployment payments.

To give an example of the data, the number of people living in the household is asked as well as the expenditures for electricity. Together with the average household price for electricity in 2008 from BDEW (2012), I can estimate the electricity consumption in dependence of the household size as illustrated in Figure 3.

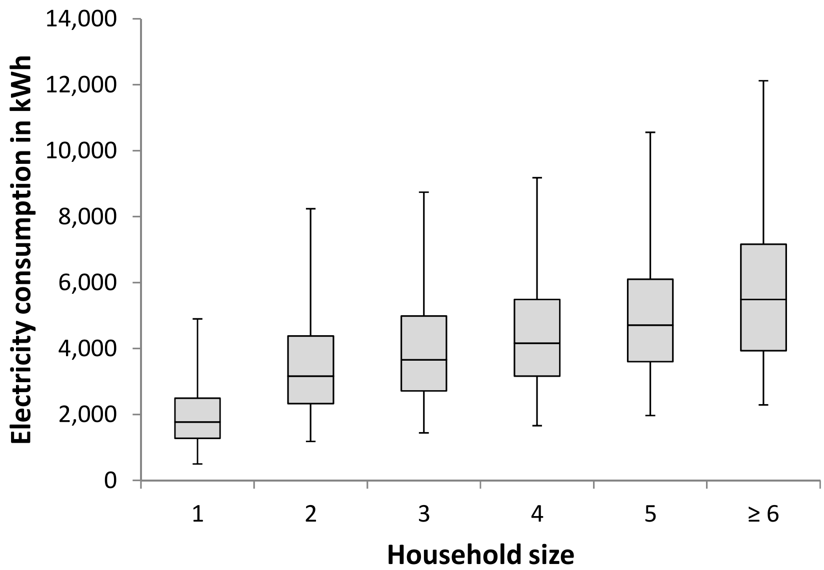

Figure 3: Annual electricity consumption and household size

4 Statistical modeling and simulation

Statistical outliers in the surveys were identified with a one-sided test of Walsh (1959) for the largest observations and excluded them from further analyses in order to avoid unnecessary bias, see Blatna (2006). Having a sample that is sufficiently large, I chose a level of significance of □=0.05 for the Walsh test. The outlier test was run on the attributes WTA and WTP outage costs. From the 841 household entries of the surveys, 18 households were eventually identified with outage costs as outliers.

From the 2008 EVS' representative 55,100 data entries for households, I excluded 2,846 data entries because of negative household incomes or non-existent electricity consumptions leaving 52,254 data entries in total.

In the process of building the following models, I tested all available parameters in the survey to identify possible significant variables for each desired model. The significant variables were then used for the models presented below.

4.1 Outage costs

On the basis of the acquired data, I created a simulation model by combining a binary discrete choice model (Probit or Logit) and a log-linear regression model and using a Monte Carlo simulation to estimate outage costs for private households based on WTA ($y_{\Delta t,WTA}$) and on WTP ($y_{\Delta t,WTP}$).

I built the model by following four steps that I describe in detail below:

1. Some of the interviewees indicated that they had no outage costs for specific interruption durations. In a first step, I therefore needed to estimate the

probabilities of occurrence $p^{y}_{\Delta t}$ that a household has outage costs different to zero for the analyzed interruption duration. To do so, I used a binary discrete choice regression model.

$$y_{\Delta t} = X \cdot y^{*}_{\Delta t} \text{ und } \begin{cases} X = 0 & \text{mit } p(X = 0) = 1 - p^{y}_{\Delta t} \\ X = 1 & \text{mit } p(X = 1) = p^{y}_{\Delta t} \end{cases}$$

2. In a second step, I needed to estimate the WTA based outage costs for the cases, where a household has outage costs greater than zero. For that, I chose a log-linear regression model that could be analyzed with the method of ordinary least squares (OLS), see Stocker (2012). In a previous work, see Praktiknjo et al. (2011), I assumed that outage costs are dependent on the factors *household size*, *income* and *individual preferences on the usage of free time*. For this reason, I use *household size* n_{hh} per [capita] and *monthly household net income* w_{hh} in [Euro] as regressors in the present work. Furthermore, I assumed that the *type of building the household is living in* (freestanding/duplex family house or not) bt_{dummy} [-] has an influence on the outage costs.
    - Eventually, with the assumptions made in my previous work, I chose the following functional form for the modeling of *WTA based outage costs greater than zero* $y^{*}_{\Delta t,WTA}$:

$$y^{*}_{\Delta t,WTA} = const \cdot n_{hh}^{\alpha} \cdot w_{hh}^{\beta} \cdot e^{\gamma \cdot bt_{dummy}}$$

$$\ln(y^{*}_{\Delta t,WTA}) = \ln(const) + \alpha \cdot \ln(n_{hh}) + \beta \cdot \ln(w_{hh}) + \gamma \cdot bt_{dummy}$$

- I assumed that *WTP outage costs greater than zero* $y^*_{\Delta t,WTP}$ are dependent on *WTA outage costs* $y^*_{\Delta t,WTA}$. This is why I chose the following functional form:

$$y^*_{\Delta t,WTP} = const \cdot {y^*_{\Delta t,WTA}}^{\alpha}$$

$$\ln(y^*_{\Delta t,WTP}) = \ln(const) + \alpha \cdot \ln(y^*_{\Delta t,WTA})$$

3. In a third step, I estimated the parameters of the model, meaning for the binary and the OLS part of the models. I did so for each of the five different outage durations I chose to observe in the survey. Furthermore, I analyzed the OLS' residuals $\hat{u}_{\Delta t}$ and fitted them to distribution functions.

4. In the fourth and final step, I first derived estimations about the average WTA and WTP outage costs by applying the model estimated in the third step on the remaining 52,254 data entries of the EVS described in section 3.2, resulting in large datasets for each model with 52,254,000 data entries each. To take the uncertainties associated with the parameter estimations of the model into account, I implemented a Monte Carlo simulation to estimate the population's outage costs. In order to do so, I used the fitted distribution functions of the OLS' residuals and repeated the sampling 1,000 times.

$$y^*_{\Delta t,WTA} = const \cdot n_{hh}^{\alpha} \cdot w_{hh}^{\beta} \cdot e^{\gamma \cdot bt_{dummy}} \cdot e^{\hat{u}_{\Delta t,WTA}}$$

After having estimated the total WTA and WTP based outage costs, I wanted to estimate the VOLL and the shares of these costs c_i in each of the four surveyed areas of inconveniences.

The VOLL was estimated by dividing the *total outage costs* $\mathrm{y}_{\Delta \mathrm{t}}$ with *annual electricity consumptions* EC in the *considered time frame* $\Delta\mathrm{t}$. With $\Delta\mathrm{t}$ in hours, following formula was used:

$$\mathrm{VOLL}_{\Delta \mathrm{t}} = \frac{\mathrm{y}_{\Delta \mathrm{t}}}{\frac{\mathrm{EC} \cdot \Delta \mathrm{t}}{8.760}}$$

As a reminder, the four analyzed areas of inconveniences were spoilage of food, limitation of household activities, data losses and comfort issues (see

). I used the subjective assessments from the surveyed individuals I_i on a scale from 0 to 10 to derive these shares for the different outage durations.

$$\mathrm{c_i} = \frac{\mathrm{I_i}}{\sum_{\mathrm{i}=0}^{\mathrm{i}=4} \mathrm{I_i}}$$

Furthermore, I wanted to describe these shares on the outage costs with a linear OLS model if possible. I tried all available regressors to identify a suitable model that describes the distribution of these inconveniences.

4.2 Preferences for supply security in the context of climate protection and nuclear energies

Some of the surveyed individuals were asked to state their personal preferences regarding supply security in the context of climate protection and nuclear energies following the nuclear catastrophe in Fukushima in Japan. The individuals had to choose between five ranked options for each topic (see Table 2). Because of these ordered choices, I decided to estimate the probabilities using ordered Probit models. For more information on discrete choice models see Train (2009) and on ordered choice models see Greene and Hensher (2010). The implemented model consists of these three steps described below.

1. As regressors for *preferences between supply security and climate protection* $y_{Cli,OL}$ I used *household size* n_{hh} per [capita], *annual electricity consumption* EC in [kWh] and the *building type* bt_{dummy} [-].

$$y_{Cli} = f_{OP}(y^*_{Cli})$$

$$y^*_{Cli} = \alpha \cdot n_{hh} + \beta \cdot EC + \gamma \cdot bt_{dummy}$$

   As for the comparison of *preferences between supply security and a nuclear phase out* $y_{Nuc,OL}$ I used the *preferences between supply security and climate protection* y_{Cli} as regressor.

$$y_{Nuc} = f_{OP}(y^*_{Nuc})$$

$$y^*_{Nuc} = \alpha \cdot y^*_{Cli}$$

2. After having estimated the models' parameters, I analyzed the distribution of the regressions' residuals. An important requirement for the application of the Probit model is that the residuals are distributed normally.

3. With the estimated model and the associated cut-off points, I used the data provided from DESTATIS (2008) to calculate the probabilities for each choice of the 52,554 households regarding the preferences for supply security in the context of climate protection and nuclear energies. Out of these probabilities I derived the average probability for each choice as a Maximum-Likelihood estimator for the population's share regarding preferences on supply security in the context of climate protection and a nuclear phase out.

5 Results of the modeling and simulation

After having specified the statistical models and simulations in the previous section, I present the estimated parameters in this section. Variables that have not been used in the models have been identified as insignificant. I used the econometric computer software Gretl for the models' estimations and the statistic software R to perform the Monte Carlo simulations.

5.1 Outage costs

For the WTA and WTP model's binary discrete choice part, I used all available variables of the survey to identify proper significant relationships. With this given setting, I was unable to identify significant models. The McFadden coefficient of determination was always below a level of one percent. Eventually, I chose to use the distributions obtained in the surveys to describe the probabilities of a household having WTA and WTP outage costs greater than zero, see Figure 4.

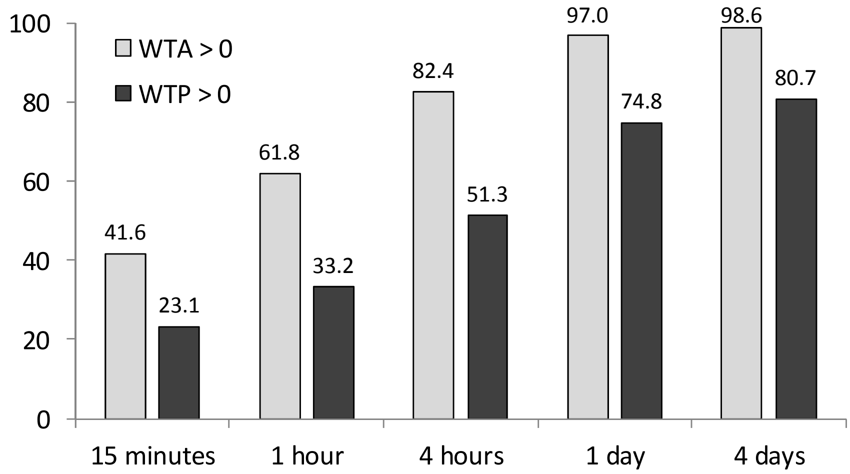

Figure 4: Shares of WTA and WTP outage costs greater than zero in percent

The estimation of the parameters of the model's OLS part was more successful. The parameter estimations of the OLS part for WTA and WTP based outage costs are shown in Table 3. Interestingly, the dummy variable $\mathrm{bt_{dummy}}$ was only significant for outage durations of at least 4 hours. For that reason, I chose a coefficient for the dummy variable $\mathrm{bt_{dummy}}$ in the case of outage durations below 4 hours with $\gamma = 0$ and estimated the parameters for outage durations of at least 4 hours with OLS.

As a reminder, the model's OLS part for WTA based outage costs was

$$\ln(y^*_{\Delta t,\mathrm{WTA}}) = \ln(\mathrm{const}) + \alpha \cdot \ln(n_{\mathrm{hh}}) + \beta \cdot \ln(w_{\mathrm{hh}}) + \gamma \cdot \mathrm{bt_{dummy}}$$

For WTP based outage costs, the model's OLS part was

$$\ln(y^*_{\Delta t,\mathrm{WTP}}) = \ln(\mathrm{const}) + \alpha \cdot \ln(y^*_{\Delta t,\mathrm{WTA}})$$

Table 3: Parameter estimations for the WTA and WTP outage costs model

		WTA				WTP		
			Coeff.	p-value			Coeff.	p-value
15 minutes	p(WTA>0) = 42 %	ln const.	-0.0292	0.97	p(WTP>0) = 23 %	ln const.	0.8186	0.00
		α [n_{HH}]	0.8608	0.00				
		β [w_{HH}]	0.2595	0.01		α [y^*_{WTA}]	0.6589	0.00
		γ [bt_{dummy}]	0.000*	-				
		p-value	0.00			p-value	0.00	
		Adj. R²	0.17			Adj. R²	0.41	
			Coeff.	p-value			Coeff.	p-value
1 hour	p(WTA>0) = 62 %	ln const.	0.9554	0.07	p(WTP>0) = 33 %	ln const.	0.7357	0.00
		α [n_{HH}]	0.9824	0.00				
		β [w_{HH}]	0.1823	0.01		α [y^*_{WTA}]	0.6728	0.00
		γ [bt_{dummy}]	0.000*	-				
		p-value	0.00			p-value	0.00	
		Adj. R²	0.18			Adj. R²	0.44	
			Coeff.	p-value			Coeff.	p-value
4 hours	p(WTA>0) = 82 %	ln const.	1.6671	0.00	p(WTP>0) = 51 %	ln const.	0.9085	0.00
		α [n_{HH}]	0.9367	0.00				
		β [w_{HH}]	0.1686	0.00		α [y^*_{WTA}]	0.6121	0.00
		γ [bt_{dummy}]	0.3491	0.01				
		p-value	0.00			p-value	0.00	
		Adj. R²	0.23			Adj. R²	0.42	
			Coeff.	p-value			Coeff.	p-value
1 day	p(WTA>0) = 97 %	ln const.	1.0496	0.04	p(WTP>0) = 75 %	ln const.	0.8191	0.00
		α [n_{HH}]	1.0891	0.00				
		β [w_{HH}]	0.3259	0.00		α [y^*_{WTA}]	0.6344	0.00
		γ [bt_{dummy}]	0.4017	0.00				
		p-value	0.00			p-value	0.00	
		Adj. R²	0.26			Adj. R²	0.45	
			Coeff.	p-value			Coeff.	p-value
4 days	p(WTA>0) = 99 %	ln const.	1.9619	0.00	p(WTP>0) = 81 %	ln const.	0.939	0.00
		α [n_{HH}]	1.0614	0.00				
		β [w_{HH}]	0.3615	0.00		α [y^*_{WTA}]	0.6075	0.00
		γ [bt_{dummy}]	0.3804	0.00				
		p-value	0.00			p-value	0.00	
		Adj. R²	0.26			Adj. R²	0.44	

After 1,000 runs of the Monte Carlo simulation, 52,254,000 data entries for WTA and WTP outage costs each for private households were received. The simulations' results are shown as boxplots in Figure 5 in dependence of the interruption duration. For the boxplots, I chose 0.05 and 0.95 percentiles as whisker boundaries. These boxplots show that the distribution of the simulated outage costs is right skewed for WTA and WTP, as the discrepancies between mean averages and medians show.

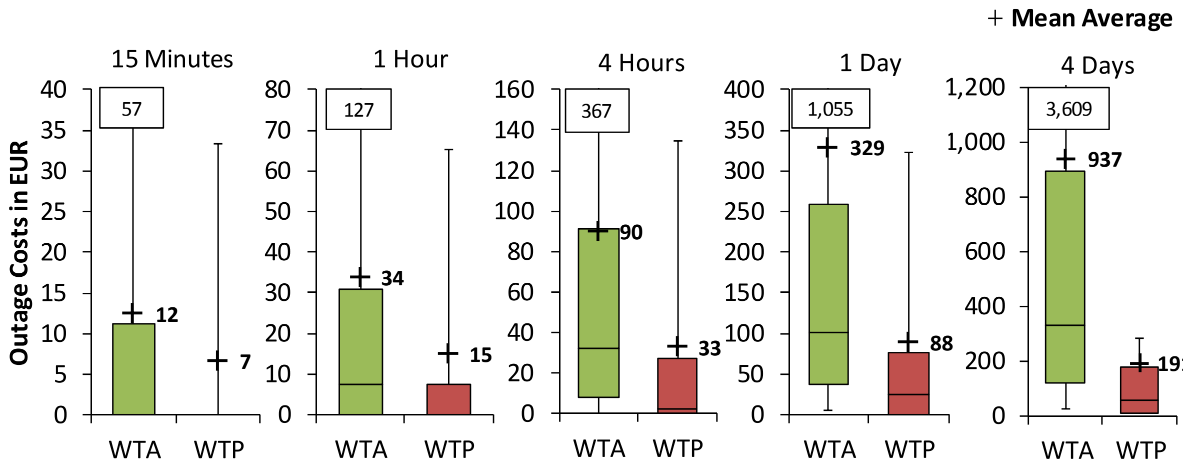

Figure 5: Distribution of WTA and WTP based outage costs in dependence of the outage duration

I also calculated the respective figures for the WTA and WTP based VOLL belonging to the simulation's results. Figure 6 shows the distribution of the calculated figures for VOLL in dependence of the interruption's duration.

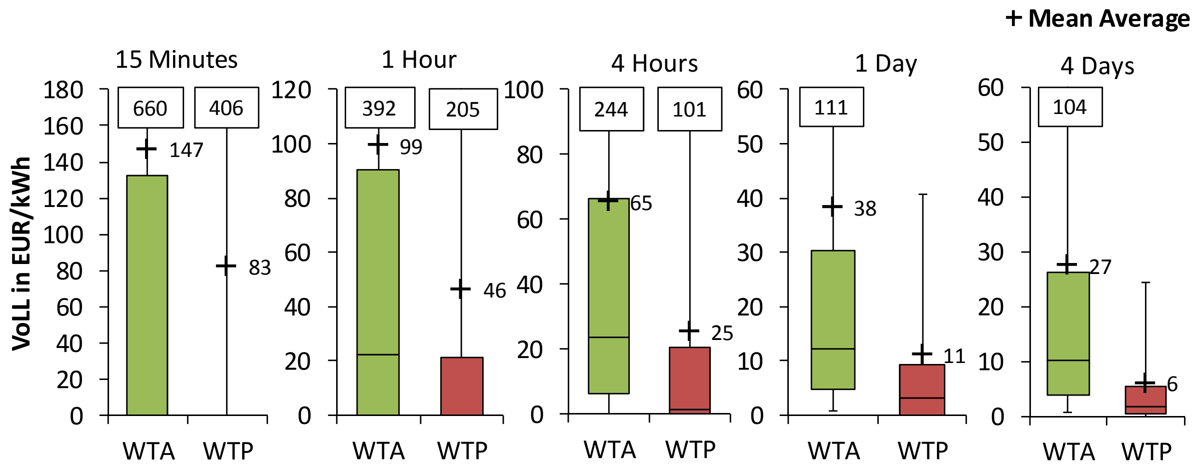

Figure 6: Distribution of WTA and WTP based VOLL in dependence of the outage duration

Furthermore, I calculated the ratios of the average WTA to WTP outage costs in dependence of the outage duration. These ratios are shown in Table 4.

Table 4: Ratios of mean averages for WTA to WTP outage costs for different outage durations

	15 minutes	1 hour	4 hours	1 day	4 days
ratio WTA/WTP	2.1	2.7	3.1	3.5	5.2

Using the available regressors (see Table 1) to estimate the shares in the different areas of outage costs with OLS, I was regrettably unable to find suitable models where I can describe the variances well enough. The coefficients of determination were all below a level of two percent, so that I eventually decided to choose the distributions I obtained through the survey instead. By doing so, I obtained the distribution of the shares in dependence of the outage duration shown in the boxplots of Figure 7.

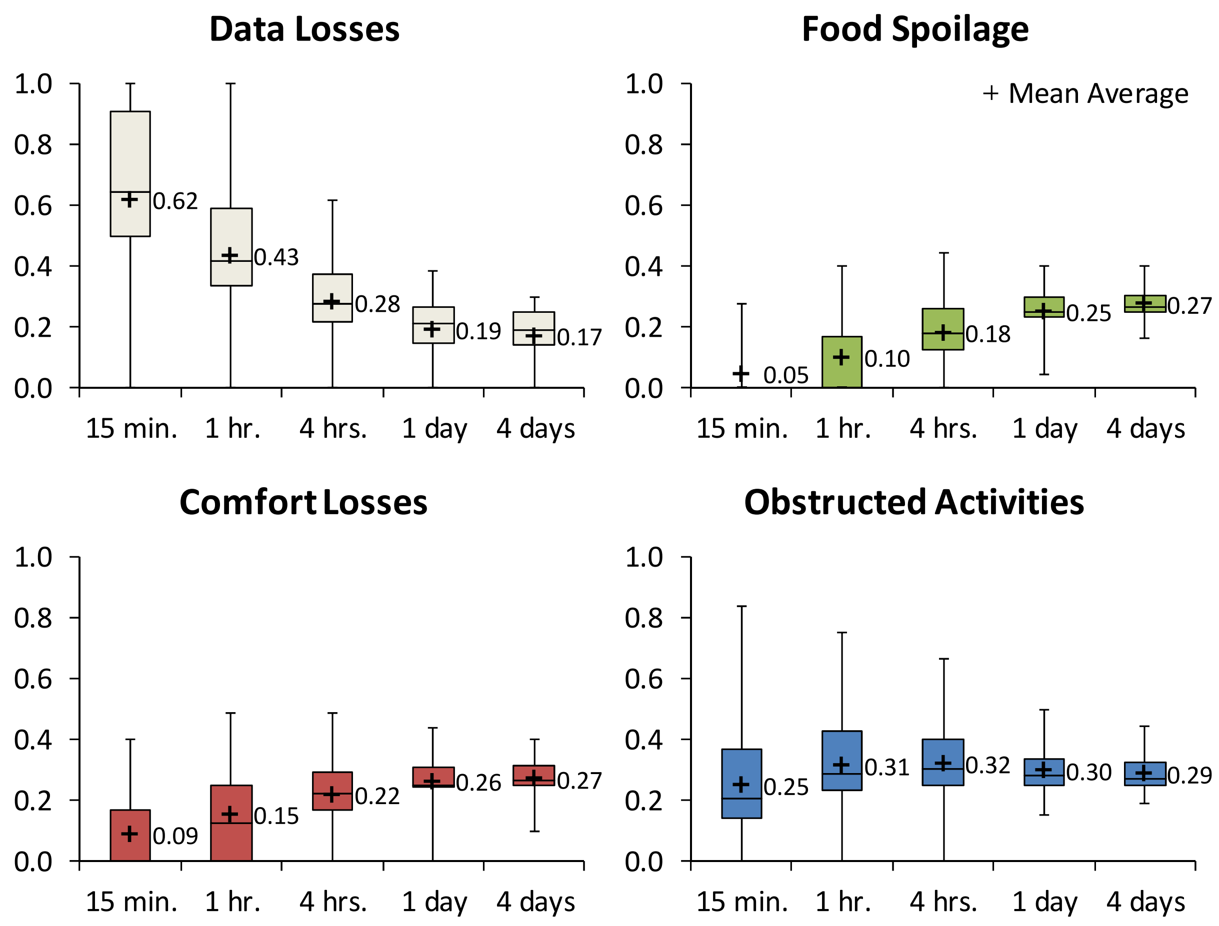

Figure 7: Distribution of the shares of inconveniences on outage costs in dependence of the outage duration

5.2 Preferences for supply security in the context of climate protection and nuclear energies

The parameter estimations of the ordered Probit model for preferences on supply security in the context of climate protection are shown below in Table 5 and Table 6. The parameter estimations for the Probit model regarding a nuclear phase out are shown in Table 7 and Table 8. The residuals for both cases have been tested for normality using a Chi-square test statistic with positive results.

Table 5: Parameter estimations for the ordered Probit model regarding Climate Protection

Climate Protection	α [n_{HH}]	β [EC/1000]	□ [bt_{dummy}]	p value
Coefficient	**-0.17**	**0.06**	**0.49**	0.0%
p value	0.4%	0.4%	0.5%	

Table 6: Estimation of the cut-off points for the Probit model regarding Climate Protection

Climate Protection	from 1 to 2	from 2 to 3	from 3 to 4	from 4 to 5
Cut-off points	**-1.08**	**-0.35**	**0.95**	**1.62**
p-Wert	0.0%	4.8%	0.0%	0.0%

Table 7: Parameter estimations for the ordered Probit model regarding a Nuclear Phase out

Nuclear Phase Out	α [y^*_{cli}]	p value
Coefficient	**0.86**	0.0%
p value	0.0%	

Table 8: Estimation of the cut-off points for the Probit model regarding a Nuclear Phase out

Nuclear Phase Out	from 1 to 2	from 2 to 3	from 3 to 4	from 4 to 5
Cut-off points	**1.91**	**2.48**	**3.11**	**3.78**
p-Wert	0.0%	0.0%	0.0%	0.0%

The results for the public opinion on supply security in the context of climate protection are shown in Figure 8 whereas the results in the context of nuclear energies are shown in Figure 9.

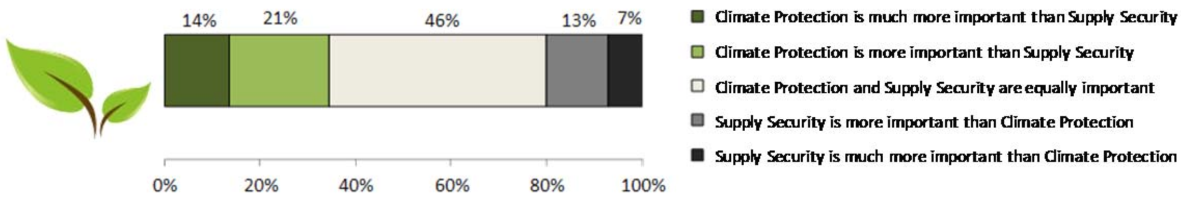

Figure 8: Public opinion on supply security in the context of climate protection

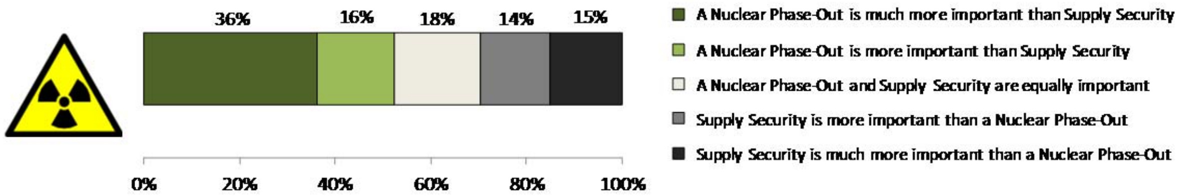

Figure 9: Public opinion on supply security in the context of nuclear energies

6 Discussion of the results

6.1 Outage costs and VOLL in dependence of the outage duration

The results support the hypothesis of my previous work, see Praktiknjo et al. (2011), that outage costs in private households are dependent on the household size and income.

The results also support the initial assumption that WTA and WTP based outage costs are both increasing with the duration of the interruption. However, this is not the case for the WTA and WTP based VOLL. Figure 6 reveals that the VOLL is decreasing instead of increasing with the duration of the interruption for both VOLL, WTA and WTP based. VOLL represents the average outage costs. Thus, the average outage costs are decreasing with the interruption's duration. Combining both observations that overall costs are increasing and average costs are decreasing, I can conclude that marginal outage costs must be decreasing with an outage's duration.

Having decreasing marginal costs is equal to having positive economies of scale in the economic production theory, see Varian (2009). For my outage costs study, this means that in average, each additional time period of an outage is less costly than previous time periods. An explanation of this can be that during a blackout, a household has a certain amount of fixed costs that are constant regardless of the outage's duration.

$$C_{total}(\Delta t) = C_{fix} + C_{var}(\Delta t)$$

with $\frac{dC_{fix}}{d\Delta t} = 0$ and $\frac{dC_{var}(\Delta t)}{d\Delta t} > 0$

Analyzing the shares of the four areas of inconveniences on total outage costs, I observe indeed that for short interruption durations *data losses* are in average rated with the highest share on outage costs. The relative share of these costs decreases with enduring outage duration from about 62 (15 minutes duration) to about 17 percent (4 days duration) in average. In the context of private households, *instant data losses* can in fact be considered as costs being generally independent to the outage duration.

The average share on outage costs for the areas of inconveniences *food spoilage* and *comfort losses* however increases with the duration of the power interruption. For *food spoilage* it increases from about 5 (15 minutes blackout) to about 27 percent (4 days blackout). For *comfort losses* it increases from about 9 (15 minutes) to about 27 percent (4 days).

The *inability to perform activities* at home has a more or less constant share on outage costs for durations between 15 minutes and 4 days. The share varies from about 25 (15 minutes) to about 32 (4 hours) and re-decreases to about 29 percent (4 days).

Comparing the average VOLL ranging from 2.28 to 79.92 in average (depending on WTA or WTP and outage duration) to the household price for electricity in 2011, which was at about 0.25 Euro/kWh in average according to BDEW (2012), I can conclude that electricity holds a very important position in private households. Yet, I notice that the estimated distributions for outage costs and VOLL figures are strongly right skewed. This means that a large majority of the population has relative low outage costs compared to a minority of the population that has very high outage costs.

The WTA to WTP ratio in Table 4 show that WTA based outage costs are significantly higher than WTP based outage costs. I also observe that the WTA to WTP ratio increases with longer outage durations from a factor of 2 for a 15 minutes blackout to a factor of 5 for a blackout of 4 days.

Following the theory from Hanemann (1991) described in section 2, I conclude that the high disparity between WTA and WTP indicate that the substitutability for the good electricity with other goods is being considered very low. Moreover, the increasing gap between WTA and WTP indicates that the substitutability decreases even further with ongoing outage duration in private households.

6.2 Preferences on supply security in the context of climate protection and nuclear energies

The estimated shares on preferences regarding supply security and climate protection indicate that the majority of the population, with a share of about a half, sees supply security being as important as climate protection. Furthermore, one third of the population prefers climate protection over supply security whereas only a sixth of the population prefers supply security over climate protection. These figures indicate that the population does not tolerate a decrease of supply security in favor of climate protection as about two third of the population considers supply security as at least equally important to climate protection. I conclude that the integration of a growing share of renewable energies at the expense of supply security is not supported by the majority of the population.

The figures for the shares of preferences regarding supply security and nuclear energies are different. The majority of the population, with a share of over a half, considers a phase out of nuclear energies as more important than supply security. A sixth of the population considers a phase out of nuclear energies equally important as supply security whereas about a third of the population considers supply security more important than a phase out from nuclear energies. However, the interpretation of these figures should be done under the consideration that this part of the survey was carried out only a couple of days after the incidents of the nuclear catastrophe in Fukushima in Japan. There is a good possibility that the very recent nuclear catastrophe might have a significant impact on these results. But following these figures, the decision of the German government to react with a coordinated phase out of nuclear energies was a choice with the support of the population’s majority at that point in time.

7 Conclusion and outlook

Stern (2007) quantified the consequences of a climate change monetarily and suggested in a cost-benefit-analysis that a climate change induces economic costs which are higher than the mitigation costs for an environmentally sustainable economy.

Following this logic, the German government decided to integrate a growing share of renewables into the electricity system. Additionally, a complete phase out of nuclear energies was decided right after the events of the catastrophe in Fukushima in 2011.

However, a decision solely based on this work of Stern, does not include the third goal of energy policy, which is energy supply security. The aim of this work is to contribute to a more holistic picture when deciding on the costs and benefits of renewables and a nuclear phase out by taking impacts on supply security into account. I analyzed the costs of blackouts as an indicator for costs of failing supply security. The focus of this work lies within residential power consumers. My results indicate that failing supply security in form of blackouts is relatively expensive for residential consumers. I also analyzed the public's opinion, which is also very fundamental to decisions in a democratic context next to costs and benefits. These results indicate that the majority of the population does not accept a lower security of supply in favor of a renewable system in the electricity sector. The two goals supply security and environmental sustainability are considered as being equally important. Both, the very high costs and the public opinion show that supply security cannot be neglected in favor of a renewable electricity system. However, following the data acquired only shortly after the nuclear catastrophe in Fukushima, more than half of the population supports a phase out of nuclear energies over supply security. In terms of public opinion, the German government made the decision of a nuclear phase out with the support of the population.

Follow-up studies could be done by analyzing outage costs for electricity consumers other than private households. Detailed estimations on the potential of demand side management (DSM) measures could then be conducted based on the monetary value of power interruptions. Another interesting aspect would be an up-to-date re-evaluation of the public opinion on supply security in the context of nuclear energies now that more time has passed after the nuclear catastrophe in Japan.

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